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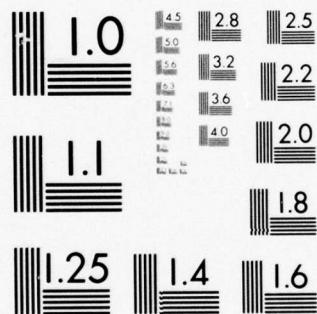
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**THE FEASIBILITY AND APPLICATIONS OF
A COMPUTER BASED SYSTEM FOR
ELECTRONIC TEST EQUIPMENT AND
BASIC ELECTRONICS TRAINING**

**Prepared for:
NAVAL AIR DEVELOPMENT CENTER
Warminster, Pennsylvania 18974**

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20. simulation-based system indicated that the simulation approach is cost-effective. Finally, a demonstration of the technical feasibility of simulation-based basic electronics training was designed and implemented. It was concluded that a simulation approach to basic electronics and test equipment training is technically feasible, cost-effective, and would improve training effectiveness.



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PREFACE

The authors extend their appreciation to Mr. Len Lorence, Research Scientist, Dr. T.P. Coleman, Computer Applications Engineer, Mr. Michael Lyons, Technician, and Mr. Kurt Graffunder, Research Associate, for their numerous technical contributions to this program.

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SUMMARY

The purpose of this study was to examine the cost and technical feasibility of applying a simulation-based basic electronics training system to a Navy BE and E School. Life cycle costs of the San Diego BE and E School were analyzed to identify key points of leverage for cost savings. An alternative simulation-based training system for the school was then conceptually designed and life cycle costs for that system were estimated. Finally, the life cycle costs of the current BE and E training system were compared with the costs of the alternative simulation-based system, and potential savings were estimated. The study also included the design and implementation of a feasibility demonstration based on a representative segment of the BE and E course.

The results of the study indicated that the costs associated with current Navy Basic Electricity and Electronics training are largely (94 percent) personnel-related. Equipment/maintenance cost savings were demonstrated when currently used equipment was compared in the cost model with a simulation-based system. However, those savings were small in comparison with the total life cycle cost of BE and E training. On the other hand, the simulation-based system has the potential for substantially reducing student-related costs through the reduction of on-board time and attrition rate.

It was concluded that simulation-based basic electronics training is technically feasible, would provide more effective training, and has the potential for yielding substantial life cycle cost savings. Recommendations are made for continued evaluation of the concept through the development of a prototype training system.

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SECTION I

INTRODUCTION AND STATEMENT OF THE PROBLEM

A vast majority of Naval electronic systems contain complex circuitry which can be checked out and maintained only by using sophisticated test equipment. For the Navy training establishment, this means that maintenance technicians must develop highly refined skills to use such equipment.

According to reports, Navy trainees entering advanced or "C" school maintenance training frequently lack the basic skills (for instance, test equipment operation) needed to learn maintenance of complex electronic systems. A recent view of Navy EW maintenance training programs for example, pointed out, "Each equipment-specific training activity contacted or visited. . .agreed that the entering student mainly lacks proficiency in maintenance test and measurement skills and knowledge. The training activities strongly feel that by correcting this deficiency a major training burden would be removed from the "C" schools."¹

¹Pearson, T.E., et al., Electronic Warfare Maintenance Training Analysis. TAEG Report 9-2. Training Analysis and Evaluation Group, NTEC, Orlando, Florida. March, 1974, p. 33.

Ideally, Navy trainees should develop proficiency in basic test equipment use and circuit analysis during the Basic Electricity and Electronics (BE and E) training sequence. Currently, 40 percent of the trainee's time in BE and E School is devoted to hands-on laboratory experience using operational test equipment and training devices with operational circuitry. However, the effectiveness of current laboratory training procedures is limited by six major difficulties:

- 1) The high instructor/student ratio (1:10 at the BE and E School, San Diego) results in a lack of direct performance monitoring.
- 2) Feedback techniques are nonexistent or inefficient. The student must perform the hands-on manipulations described in the laboratory manual without knowing whether or not his manipulations are correct.
- 3) Mil-spec operational equipment is required, resulting in high procurement and maintenance costs.
- 4) Trainees must perform numerous and time-consuming hands-on procedures unrelated to the training objectives, simply to ready the operational training devices for study.
- 5) Malfunctions are limited and often non-representative. Due to their manner of presentation, the malfunctions are obvious and readily identified by trainees with little or no systematic testing of the circuit.
- 6) The use of operational equipment frequently involves dangerous voltages, which pose safety problems to the students and equipment.

These limitations to effective training highlight the need for new, innovative, cost-effective techniques for basic test equipment and electronics training. The limitations and high cost associated with the use of operational equipment have brought about an increasing emphasis on simulation within the military training establishment. Simulation has been previously shown to reduce the problems in flight training² and advanced level electronics maintenance training.^{3, 4, 5} Thus, the use of simulation in basic electronics electronics and test equipment training is potentially an attractive alternative to the use of operational equipment.

²Roscoe, S.N., *Effective and Economical Simulation in the Design and Use of Aerosystems*. Technical Report ARL-75-8/AFOSR-75-3. Aviation Research Laboratory, University of Illinois at Urbana-Champaign. April, 1975.

³Miller, G.G., *Some Considerations in the Design and Utilization of Simulators for Technical Training*. Technical Report Number AFHRL-TR-74-65. Air Force Human Resources Laboratory, Lowry Air Force Base, Colorado. August, 1974.

⁴Daniels, R.W., et al., *Feasibility of Automated Electronic Maintenance Training (AEMT) Volume 1 - Design, Development, and Evaluation of an AEMT/ALQ-100 Demonstration Facility*. Technical Report NADC 75176-40. Naval Air Development Center, Warminster, Pennsylvania. May, 1975.

⁵Daniels, R.W., and Cronin, J.E., *Feasibility of Automated Electronic Maintenance Training (AEMT) Volume 2 - Cost Analysis*. Technical Report NADC 75177-40. Naval Air Development Center, Warminster, Pennsylvania. May, 1975.

PROGRAM PURPOSE

The purpose of this program was to investigate the cost and technical feasibility of applying simulation techniques to Navy Basic Electricity and Electronics (BE and E) training. Specifically, the program was undertaken to:

- 1) Analyze the life cycle costs of Navy Basic Electricity and Electronics training.
- 2) Conceptually design and cost an alternative computer and simulation based basic electronics training system.
- 3) Compare the costs of current training with those associated with the simulation based system.
- 4) Demonstrate the feasibility of simulation based basic electronics training.

The program focused on the Basic Electricity and Electronics School located at the Naval Training Center, San Diego, California. The San Diego BE and E School is one of four such facilities (others are located at Memphis, Great Lakes, and Orlando) and handles approximately 28 percent of the total Navy BE and E trainee load. The school represents one of the first attempts by the Navy to apply self-paced/computer-managed instruction methods to maintenance training. The CMI system is primarily used to score tests and manage student records. , Finally, the BE and E program at San Diego provides both classroom study and hands-on laboratory experience (in roughly equivalent amounts) for approximately 7000 entrants per year. The attrition rate is 14 percent.

SECTION II

RESULTS

LIFE CYCLE COST ANALYSIS

Cost data for the Basic Electricity and Electronics School, Naval Training Center, San Diego were collected by a team of Honeywell scientists during a visit to that facility on 12-14 July, 1976. Interviews were conducted and data collected to determine:

- Building and occupancy costs
- Equipment and maintenance costs
- Instructional material costs
- School personnel costs
- Student costs

Cost data were analyzed and entered into a model similar to the TECEP (Training Effectiveness and Cost Effectiveness Program) model developed by the Navy's Training Analysis and Evaluation Group. The elements of the TECEP model are presented in Table 1. The model used in the present study differed from the TECEP model in that personnel costs associated with equipment maintenance were included in the Equipment rather than the Personnel category. Costs associated with office supplies and instructional materials were included in the Equipment and Instructional Materials categories, respectively, rather than as a separate supply category.

Table 1. TECEP Cost Model⁶

$$C_{\text{MBY}} = C_{\text{FAC}} + C_{\text{EQU}} + C_{\text{IMD}} + C_{\text{PRS}} + C_{\text{SUP}} + C_{\text{STD}}$$

Where:

COST	C_{MBY} = Total media based cost per year per student position.
FACILITIES	C_{FAC} = Cost of facilities per year per student position.
EQUIPMENT	C_{EQU} = Cost of equipment per year per student position.
INSTRUCTIONAL MATERIAL	C_{IMD} = Cost of instructional materials development per year per student position.
PERSONNEL	C_{PRS} = Yearly cost per student position of instructional, support, and administrative personnel, including salary, benefits, recruiting, training, travel, subsistence, and other associated costs.
SUPPLIES	C_{SUP} = Yearly cost of all student, instructor, office, and miscellaneous supplies per student position including student instructional materials (prorated portions if used by more than one student).
STUDENTS	C_{STD} = Yearly cost of students per student position including wages, benefits, travel, subsistence, and other similar or associated costs.

⁶Reproduced from Braby, R., et al., A Technique for Choosing Cost-Effective Instructional Media. TAEG Working Draft. Training Analysis and Evaluation Group. Orlando, Florida. April, 1974.

The following assumptions were made in analyzing the data:

- Personnel and student costs were based on Bureau of Personnel life cycle personnel costs
- Costs reflected in now-year (1976) rates
- Trainee Load: 7000 entrants/year
 1000 drop-outs/year
 6000 graduates/year
- Average on-board time: graduates = 1.5 months
 drop-outs = 0.5 months
- Building depreciated over 30 years
- Laboratory equipment depreciated over 10 years.

Table 2 shows a summary of life cycle costs of the BE and E School at San Diego. Within each of the cost categories, there is one more level of detail. The detailed cost data are presented in Table 3, which will serve as the basis for discussion of the results.⁷

⁷ The reader is directed to Appendix A for a detailed account of the cost calculations on which Table 3 is based.

Table 2. Summary of Life Cycle Costs for the
BE and E School, San Diego

	Per Year Cost	Percent of Total
Facilities	\$319,656	2.0
Equipment	848,916	5.0
Instructional Material	\$258,703	1.5
School Personnel	\$2,764,608	17.0
Students	<u>\$12,219,083</u>	<u>74.5</u>
Total Training Costs	\$16,410,966	100.0
Average Cost per Graduate	\$2,735	

Tables 2 and 3 show that building costs represent only a minute portion of the total training cost. Occupancy/maintenance costs for the BE and E School building per se were not available from the base comptroller, so an average occupancy cost per square foot (\$3.22 estimated on Oceana Naval Air Maintenance Training Detachment costs) was applied to the BE and E facility and entered into the model.

Equipment and related costs surprisingly account for only 5 percent of the total cost in the current BE and E system. Over half of the equipment costs are represented by the school's CMI system which is rented on a monthly basis. Maintenance costs are based on an expenditure of nine man-years per year of E-6 grade technical labor, and represent approximately 30 percent of total equipment costs. A major portion of the maintenance expenditure is devoted to repair and calibration of the school's oscilloscopes which have an estimated MTBF of one week.

Table 3. Detailed Life Cycle Cost Estimates for the
BE and E School, San Diego

FACILITIES	Per Year Cost
Building Construction Cost	\$ 47,962
Building Occupancy Cost	<u>271,694</u>
Total Cost	\$319,656
EQUIPMENT	
Office	\$ 3,700
Carrels	5,265
Test Equipment	60,574
Training Devices	26,035
Spares	17,322
Maintenance	239,724
CMI System	
Optical Scanning Equipment	234,900
Computer System	<u>261,396</u>
Total Cost	\$848,916
INSTRUCTIONAL MATERIAL	
Instructional Development Group	\$ 241,903
Personnel	
Printing/Reproduction	<u>16,800</u>
Total Cost	\$ 258,703

Table 3. Detailed Life Cycle Cost Estimates for the
BE and E School, San Diego (concluded)

SCHOOL PERSONNEL

Instructors	\$1,843,072
Support	<u>921,536</u>
Total Cost	\$2,764,608

STUDENTS

Personnel Costs	\$12,114,083
Travel	<u>105,000</u>
Total Cost	\$12,219,083

TOTAL TRAINING SYSTEM COSTS

PER YEAR	\$16,410,966
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Instructional material costs are almost entirely personnel-related. The Instructional Development Group employs 30 ETs at an average grade between E-6 and E-7, resulting in a total yearly cost in excess of \$800,000. The BE and E School at San Diego bears approximately 28 percent of this total cost.

School personnel costs are based on the costs associated with 64 instructors and 32 support personnel (excluding maintenance and Instructional Development Group personnel) at an average grade between E-6 and E-7.

Nearly 75 percent of the total training system costs are associated with student salaries. Student personnel costs were based on an average student rating of E-3 and on the student load and on-board time estimates listed above. Travel costs were based on the estimate that 15 percent of the 7000 BE and E School entrants travel to San Diego at an average cost of \$100.

In summary, the estimated cost of Navy Basic Electricity and Electronics Training at San Diego is approximately 16.5 million dollars per year. The total cost of Navy BE and E training (all four sites) is nearly four times that amount, or approximately 60 million dollars per year. The life cycle cost analysis also revealed that 94 percent of the cost of BE and E training at San Diego is personnel-related. On the other hand, training equipment costs account for less than 1 percent of the total cost of training. Therefore, any attempts to substantially reduce the cost of BE and E training must focus on the major source of cost leverage: personnel costs.

ALTERNATIVE TRAINING SYSTEM CONCEPTUAL DESIGN AND COST

Approach

The conceptual design process commenced with an analysis of current BE and E training procedures and materials, followed by the development of alternative training system requirements. During the 12-14 July, 1976 visit to the San Diego site, interviews were conducted with BE and E School personnel to determine training procedures and the major problems with the current training system. Study guides, laboratory training

manuals, and a course syllabus were analyzed to define laboratory training objectives⁸ and to identify those portions of the course that would benefit from a simulation approach. The product of this analysis was a set of training system requirements that provided the basis for the actual trainer design effort. Those requirements are presented below.

1. The alternative training system must provide training equivalent to or better than the current training system.
2. The alternative training system must provide the capability for the simultaneous training of 100 students and must allow complete trainee self-pacing. The current BE and E training system at San Diego provides laboratory positions (carrells with training equipment) for approximately 100 students and is a completely self-paced system.
3. The alternative training system must provide the capability for direct monitoring of trainee performance on hands-on laboratory exercises. A major problem with current BE and E training at San Diego is a lack of direct laboratory performance monitoring. To improve training, test equipment front panel controls must be sensed for position, training device potentiometers and controls must be sensed for real-time adjustment by the trainee, and training device test points must be sensed for test equipment probe contact.

⁸ The general laboratory training objectives are included as Appendix B.

4. The alternative training system must provide realistic functional simulation of all training device circuits currently used in laboratory Modules 1-25. The tasks involved in Modules 1 and 2, Module 15-IV, and Module 16-1 will be trained using current methods rather than simulation.⁹
5. The alternative training system must provide realistic functional simulation of a needle-deflection type multimeter. The multimeter simulation must respond in a dynamic real-time manner to test point contact and potentiometer adjustment.
6. The alternative system must provide a functional oscilloscope and must generate realistic normal and abnormal signals for display on the oscilloscope in response to test point contact. Further, the system must allow the student to change the dynamic characteristics of the signal displayed on the scope by manipulating the front panel controls.
7. The alternative system must provide the trainee with immediate feedback on his test equipment and circuit manipulations and on his responses to courseware questions.
8. The system must provide the capability to monitor and score trainee performance on laboratory examinations.

⁹ See Appendix C for a list of tasks and equipment for which simulation was deemed inappropriate.

Conceptual Design

Figure 1 depicts in block-diagram form the alternative BE and E training system configuration. The basic unit in the system is an instructor station linked with 10 stand-alone student stations.

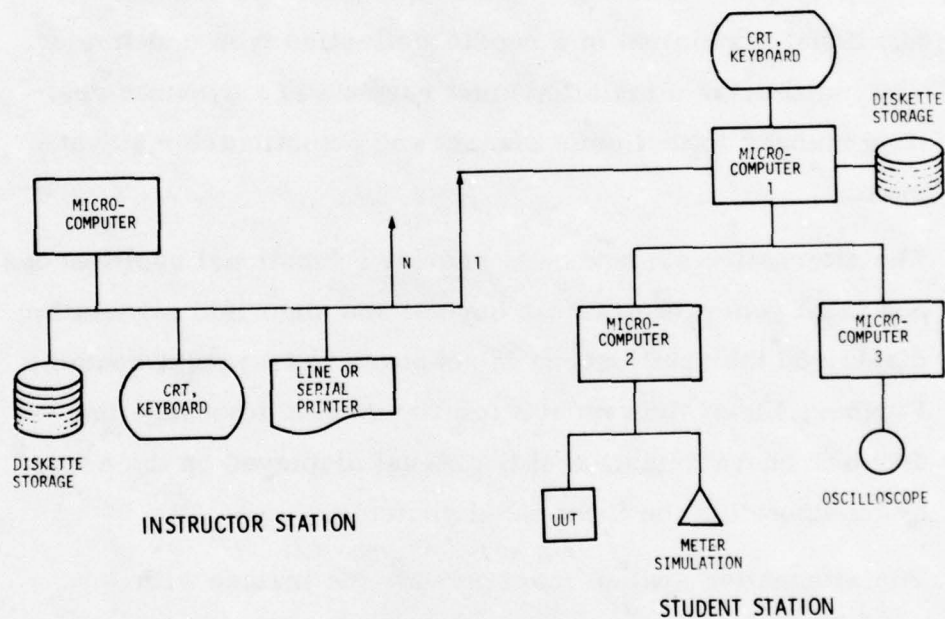


Figure 1. Simulation-based Training System Configuration

The peripheral student station equipment consists of a real oscilloscope equipped with special hardware to allow computer sensing of front panel controls. A simulated multimeter and signal generator with computer-sensed controls are also included. Finally, an array of simulated Units Under Test (UUT) is provided to replace the operational circuits currently used as training devices.

The key feature of the student station configuration is a system of three microcomputers. Microcomputer 3 is basically a ROM table for digital storage of waveform data. When called upon, Microcomputer 3 generates the appropriate digital signal which is converted to an analog form at the oscilloscope interface and then displayed on the oscilloscope.

Microcomputer 2 is dedicated to all other local aspects of the simulation. Its functions include sensing oscilloscope, multimeter, and signal generator front panel controls, sensing potentiometers, test points, and controls on the UUT's, and driving the multimeter simulation. In addition, it requests Microcomputer 3 to generate the appropriate signals. The interface between Microcomputer 2 and the periphery includes analog-digital and digital-analog conversion capability, and a rather large I-O capability.

Microcomputer 1 functions as a master controller for the student station system. It receives trainee hands-on performance data from Microcomputer 2, directs performance feedback to the trainee via the CRT and delivers performance data to the instructor station. A keyboard is provided in the configuration to allow the trainee to input answers to courseware and test questions, and other messages. Lesson material is stored on floppy discs and input into Microcomputer 1 via the diskette storage unit.

The instructor station is designed to function as a performance data storage and retrieval unit. The system is equipped with diskette storage, CRT and keyboard, line printer, and microcomputer capability. The configuration allows the instructor to retrieve the performance data for any of his ten trainees in the form of a CRT display or hard-copy print-out. In addition, it allows the instructor to monitor trainee performance on-line if he so desires.

Cost of the Alternative Training System

Costs for implementation of the simulation-based system described above fall into two categories:

- Prototype Design and Development (non-recurring) Costs
- Production (recurring) Costs

Implementation of the simulation-based system at the San Diego BE and E facility alone would involve the production of 100 trainer units. Therefore, the present costing exercise assumed that a very thorough prototype design and development effort would be essential to successful and economical system production and implementation. The following factors were included in design and development (non-recurring) cost estimates:

- Training design analysis:
 - Redesign of current BE and E course content;
 - Development of training requirements;
 - Detailed functional specification for the system
- Software design and development
- Courseware development/reformatting
- Hardware design for:
 - Instructor Station
 - Student Station
- Simulated UUT design
- Simulated test equipment design

- Hardware test plan development
- Documentation of:
 - Software
 - Hardware
 - Test plan
 - System operation
 - System maintenance
- Prototype hardware cost
- Prototype assembly and testing
- Program management

Based on these cost factors, prototype design and development (non-recurring) costs were estimated at \$400,000 to \$600,000.¹⁰

Given the student load and Instructor:Student ratio of the San Diego BE and E School, a replacement system using the conceptual design described in this report would consist of 10 instructor stations and 100 student stations. Those figures were used in the estimate of production or recurring costs. The following factors were included in that production cost estimate:

¹⁰ All estimates in the costing exercise assumed 1976 labor rates and fees.

- Hardware

100 student stations, each including:

3 microcomputers

Diskette storage unit

Interface

Oscilloscope

CRT/Keyboard

Simulated UUT's

Simulated test equipment

10 instructor stations, each including:

1 microcomputer

Diskette storage unit

Interface

CRT/Keyboard

Line printer

- Assembly
- Pre-delivery check-out
- Post-delivery check-out
- Program management

Hardware recurring costs for the system were estimated at \$2,464,000 to \$3,190,000 and recurring labor costs were estimated at \$120,000 to \$180,000. This results in a total recurring or production cost of \$2,604,000 to 3,370,000 for a 100-unit training system.

If design and development (non-recurring) costs are amortized into the production cost, the total cost of the 100-unit system is \$3,000,000 to \$3,970,000. The average cost of a single unit of the system (one student station and its portion, i.e. one-tenth, of an instructor station) is then \$30,000 to \$39,700.

LIFE CYCLE COST COMPARISON

To make the cost comparison a fair one, the following baseline parameters were established for both systems:

- Student flow
 - 7000 entrants/year
 - 1000 drop-outs/year
 - 6000 graduates/year
- On-board time
 - Graduates 1.5 months
 - Drop-outs 0.5 months
- Instructional Personnel
 - 64 Instructors (average grade = E-6-1/2)
 - 32 Support (average grade = E-6-1/2)
- Equipment depreciated over 10 years
- 100 laboratory positions
- 1976 labor rates

Table 4. Summary Level Cost Comparison of Present San Diego BE and E Training System vs. an Alternative Computer-Based System

	Current Training	Alternative System
Facilities	\$ 319,656	\$ 319,656
Equipment	848,916	715,445 - 819,045
Instructional Material	258,703	258,703
School Personnel	2,764,608	2,764,608
Students	<u>\$12,219,083</u>	<u>12,219,083</u>
Total Cost per Year	\$16,410,966	\$16,279,409 - \$16,383,009
	Net Savings	\$27,957 - \$131,557

Table 4 present a summary level comparison of life cycle costs for San Diego BE and E training using current methods versus the alternative training system. Table 4 was prepared based on demonstrable net savings associated with the Equipment category costs. One program goal was to investigate the feasibility of system justification based on equipment savings. Any additional savings from personnel costs would be attractive additions.

A detailed comparison of equipment costs in the two systems is presented in Table 5. Given the assumptions stated above, costs associated with

Table 5, Detailed Cost Comparison, Equipment Category
(San Diego Site)

	Current Training	Simulation-based System
Office	\$ 3,700	\$ 3,700
Carrells	5,265	5,265
Laboratory Equipment	86,609	302,352 - 399,352
Laboratory Spares	17,322	22,870 - 29,470
Laboratory Maintenance	239,724	119,862
CMI Computer	261,396	261,396
Optical Scanning Equipment	<u>234,900</u>	<u>0</u>
Total Cost	\$848,916	\$715,445 - \$819,045
Net Savings (San Diego site)	\$27,957 - \$131,557	

office equipment and study carrells are obviously the same in both systems. The central and nationwide record-keeping role of the CMI computer system necessitates its inclusion in both systems.

The cost of laboratory equipment associated with the alternative system is substantially greater than current equipment costs. However, those additional costs are more than balanced by the following savings. First, based on an estimated maintenance time of three man-days per year per microcomputer, and on the introduction of new non-mil-spec oscilloscopes in the alternative system, it was estimated that current man-year expenditures for maintenance would be reduced by at least one-half. Second, the alternative system was configured to provide complete test scoring and recording capability. This obviously eliminates the need for the optical scanning equipment currently used to score tests.

Laboratory spares were estimated at 20 percent of laboratory equipment value for the current system. Since fewer equipment malfunctions are anticipated in the alternative system, spares for that system were estimated at 10 percent of that hardware value for the cost comparison.

Other Potential Savings

The equipment savings demonstrated above by replacing the current with the alternative training system in the cost model are small in comparison to the total BE and E training life cycle cost. As noted earlier in this report, the key point of leverage for savings at the BE and E School lies in personnel costs. The San Diego BE and E School is currently operating with a minimum number of instructors. Therefore, life cycle cost reduction through reduction in instructor personnel is probably not feasible at the present time.

Rather, efforts to reduce personnel-related costs should be aimed at reducing costs in the student category.

Figure 2 shows the savings that result from student on-board time reduction. An average on-board time reduction per graduate of just one day, results in a savings of \$382,550 over one year at the San Diego site.

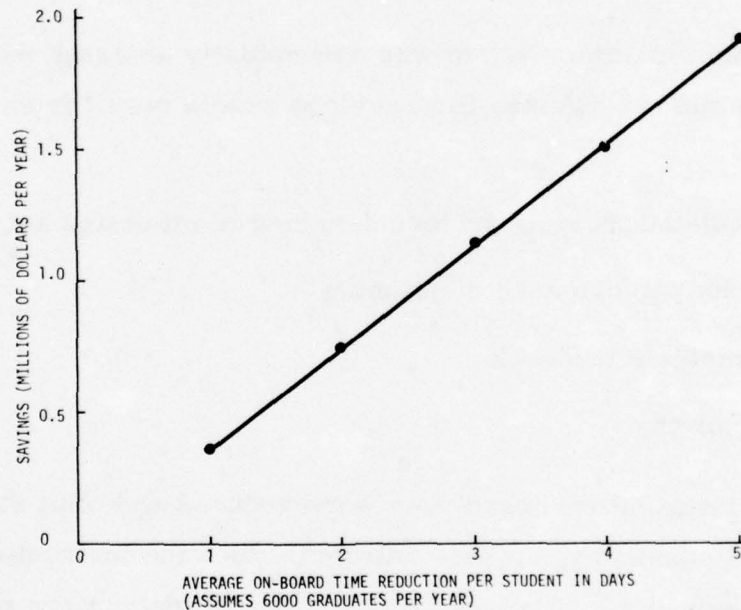


Figure 2. Savings as a Function of Student On-Board Time Reduction (San Diego Site)

This savings estimate assumes a student load of 6000 graduates per year and is measured against a current average on-board time of six weeks. Section I showed that current training techniques require trainees to perform numerous and sometimes time-consuming hands-on procedures irrelevant

to the training objectives simply to set up the operational training devices for study. Also, lacking the benefits of direct performance monitoring, immediate feedback, and prompting, it is likely that trainees in the current system are forced to spend more time solving troublesome exercises than would be necessary in a system based on more effective training techniques. Finally, frequent equipment malfunction (particularly oscilloscopes) contributes to the non-productive use of student time.

The alternative training system was conceptually designed with these problems in mind. Trainee time savings should result from that system's use of:

- simulated training devices designed to minimize set-up time
- direct performance monitoring
- immediate feedback
- prompting

Obviously, if student on-board time were reduced and total student throughput remained constant (i.e. 7000 entrants), then the Instructor : Student ratio would increase. The resulting surplus of instructors might then provide an additional point of leverage for personnel savings.

A final point of leverage in the category of student costs is the rather substantial population of students who fail to complete the course. These students clearly represent a nonproductive investment of training dollars (637,583 per year at the San Diego BE and E School). Costs related to attrition could be reduced by:

- identifying potential failures earlier in the program and dropping them from the course
- recovering and successfully training potential failures.

The use of direct performance monitoring in the alternative training system should enable instructors to identify potential failures more readily. On the other hand, with the continuous guidance provided by effective feedback and prompting techniques, a portion of those trainees who are currently dropped from the course might be able to successfully complete it. Thus, savings in this cost category are anticipated using the alternative computer-based system.

In summary, implementation of a simulation-based system at the San Diego BE and E facility would result in a net Equipment/Maintenance savings of up to \$133,475 per year. Reduction of student on-board time would result in an additional savings of \$382,550 per year for each day reduction in average on-board time. Finally, a 10 percent reduction in the attrition rate would yield a savings of \$63,758 per year. If the maximum equipment savings were experienced using simulation, on-board time were reduced by just one day, and the attrition rate were cut by 10 percent, then a net savings of \$579,783 per year would result at the San Diego site. Implementation of the simulation-based trainer at all four BE and E sites would then yield a savings of \$2,070,653 per year.

FEASIBILITY DEMONSTRATION

The technical feasibility of the key concepts involved in the alternative training system design was demonstrated by adapting a short representative segment of the BE and E course to simulation. Development of the feasibility demonstration proceeded in four distinct, but obviously overlapping phases:

- Definition of demonstration features
- Hardware design and fabrication
- Courseware development
- Software programming and demonstration implementation

Demonstration Definition

From the training system requirements developed in the conceptual design effort, some key features were selected for demonstration. The features included:

- Procedure monitoring
- Immediate feedback
- Simulated training circuits (UUT's)
- Computer-generated normal and abnormal waveforms (with dual trace capability)
- Hands-on normal and faulted circuit analysis training

Module 23, Multivibrators, was selected as a representative segment of the BE and E laboratory curriculum and provided the basis of the demonstration.

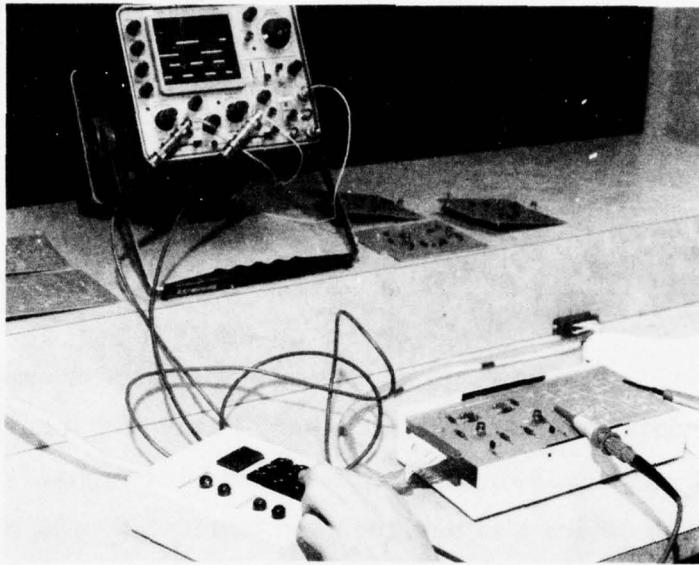
Hardware Design and Fabrication

To provide effective automated instruction, some form of student feedback display was required. It was also necessary to provide a keyboard for entry of student responses to instruction manual questions. A simple keyboard/feedback device was designed and fabricated, and is shown in Figure 3. The feedback display consists of four lights which illuminate to indicate correct or incorrect performance of a specified procedure (for example, connection of the oscilloscope probe to the correct test point) and correct or incorrect response to an instruction manual question.

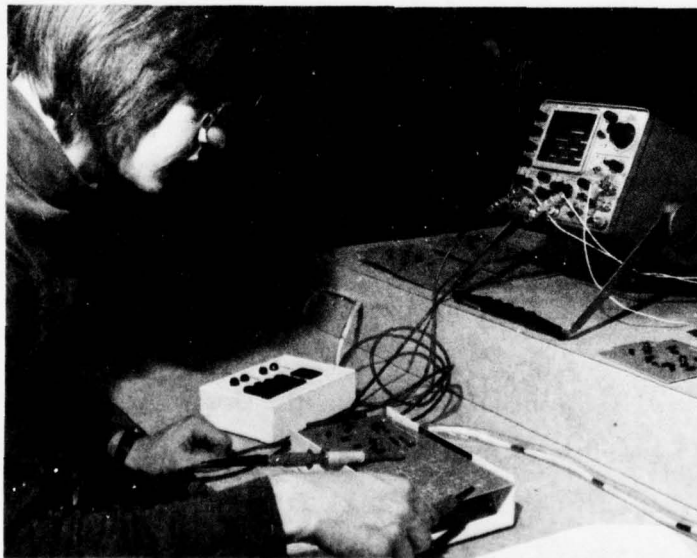
An effort was made to design UUTs that would:

- facilitate transfer of training from a schematic diagram to an actual circuit
- reduce equipment set-up time.

Figure 4 shows a UUT (one of six) from the demonstration sequence. The UUT is basically a printed circuit card with the actual circuit components mounted on the left half and the circuit schematic silk-screened on the right half. The transistor legs and the input, output, and Vcc pins on the circuit are computer-sensed, as well as corresponding test point pins mounted on the schematic half of the board. This design allows the student to connect his oscilloscope probe to a test point pin on the



a) Basic Electronics Trainer Demonstration



b) Basic Electronics Trainer Demonstration

Figure 3. Demonstration Hardware

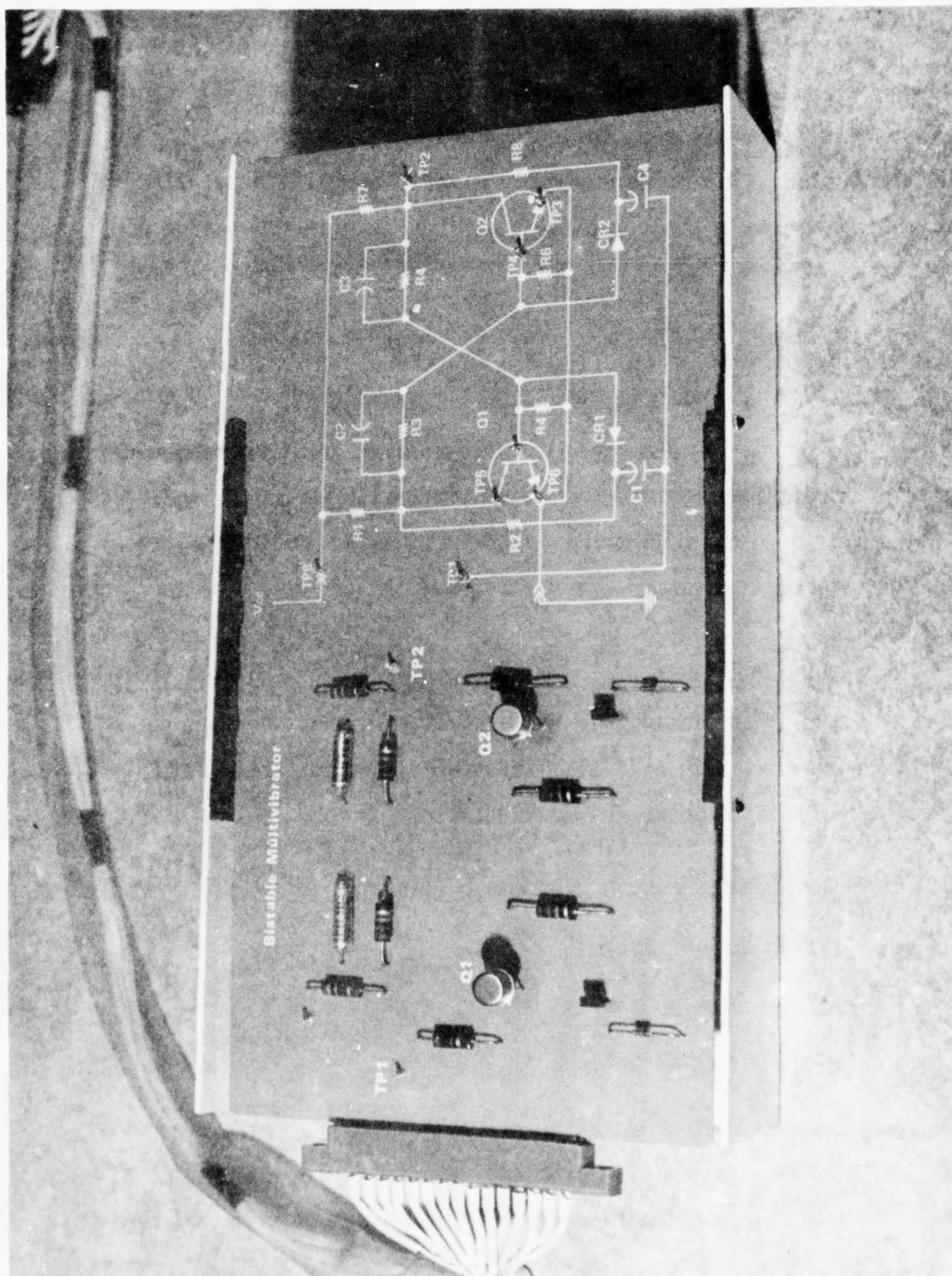


Figure 4. Unit under Test Fabricated for the Feasibility Demonstration

schematic diagram, observe the waveform, and then move the probe to the corresponding component test point on the actual circuit and again observe the waveform. Set-up time for the UUT is minimal. To set up the UUT for study, the student simply inserts the UUT card into the card holder and connects the computer cable to the card via an edge connector.

Courseware Development

As an initial step in the development of courseware, multivibrator circuits were bread-boarded and the waveforms at key circuit test points were recorded. Typical multivibrator malfunctions were identified, introduced into the bread-boarded circuits, and the abnormal waveforms were recorded.

Programmed courseware materials were written for three lessons: Astable Multivibrators; Bistable Multivibrators; Monostable Multivibrators. Each lesson included instruction in:

- Normal and faulted circuit signal tracing
- Waveform interpretation
- Schematic reading
- Multivibrator theory of operation
- Oscilloscope control adjustment

The courseware developed for the demonstration sequence is included as Appendix D.

Computer Hardware and Software

All phases of the demonstration effort proceeded on the assumption that existing Honeywell research computer facilities would be used in the demonstration. The simulation was therefore driven by an in-house computer system which included:

- A DDP-24 computer
- D/A and A/D capability
- Multiple discrete inputs and outputs

Software for the simulation and automated instruction was therefore developed on the DDP-24.

Oscilloscope Signals

The waveforms recorded from operational multivibrator circuits were coded into numeric form and stored on magnetic tape. Oscilloscope signal generation was accomplished by analog conversion of the digitally coded signals and subsequent display on a functional Tektronix 442 dual trace oscilloscope. Because test equipment front panel control sensing had already been demonstrated in another program (NADC Contract No. N62269-74-C-0111), oscilloscope controls were not monitored in the present demonstration.

Implementation and Presentation

The keyboard/feedback device, simulated units under test, oscilloscope, and cabling were installed in a study carrell similar to those used at the San Diego BE and E School. Figure 3 shows the assembled demonstration hardware in operation. The demonstration sequence was presented to Navy personnel on 15 March 1977.

SECTION III

CONCLUSIONS AND RECOMMENDATIONS

The life cycle costing exercise showed that the costs associated with current Navy Basic Electricity and Electronics training are largely (94 percent) personnel-related. Equipment/maintenance cost savings were demonstrated when currently used equipment was compared in the cost model with a simulation-based training system. However, those cost savings were small in comparison with the total life cycle cost of BE and E training. Thus, it can be concluded that a replacement system designed to meet even the most conservative equipment cost goal would not substantially impact the total BE and E training cost. On the other hand, any replacement system should have a design to cost goal of less than \$ 40,000 per trainer unit.

The key to substantial reduction of BE and E training life cycle costs is the reduction of student costs. The design goal of any replacement system for the BE and E School must be to produce a system that reduces student on-board time. Such a system should be designed to reduce irrelevant, time-consuming set-up procedures, reduce non-productive trainee time expenditure due to equipment breakdown, and should provide efficient proven automated training techniques such as direct performance monitoring, feedback, and prompting. The simulation-based training system described in this report meets these criteria and thus has the potential for reducing student-related costs. However, the magnitude of those potential savings can be accurately assessed only after evaluation of a prototype system.

Finally, a replacement system for BE and E training must be designed to maximize system availability. The design should include production hardware, modifiable software, system self-test software, and new commercial oscilloscopes.

In summary, the present study has shown that application of a simulation approach to basic electronics training is technically feasible, would provide more effective training, and has the potential for yielding substantial life cycle cost savings.

Given these results, our recommendations to the Navy are the following:

1. *Design and develop a prototype simulation-based system for BE and E training. That system should consist of one instructor station and two to five student stations.*
2. *Conduct an extensive evaluation of the cost- and training-effectiveness of the system at a BE and E training site.*
3. *If evaluation results are favorable, and substantial student cost savings can be demonstrated, pursue a production program aimed at replacement of the current training system with the simulation-based system.*

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APPENDIX A

DETAILED COST CALCULATIONS FOR CURRENT
BE AND E PROGRAM (SAN DIEGO SITE)

APPENDIX A

FACILITIES

Per Year Cost

Building Construction Cost = \$4,316,619

BE and E School uses 1/3 of building (84,377 ft²)

Depreciated over 30 years = $\$4,316,619 \div 3 \div$

30 =

\$47,962

Building Occupancy Cost

Base comptroller does not calculate occupancy/
maintenance costs per building. Therefore

Oceana cost per sq. ft. was used. \$84,377 x

\$3.22 =

\$271,694

\$319,656

EQUIPMENT

Office = \$37,000 depreciated 10 years =

\$3,700

Carrells = \$52,650 depreciated 10 years =

\$5,265

Laboratory

Test equipment = \$605,743 depreciated

10 years =

\$60,574

Training devices = \$260,353 depreciated

10 years =

\$26,035

Laboratory spares - calculated as

20 percent of equipment value over 10 years

$\$866,096 \times .2 \div 10 =$

\$17,322

Laboratory maintenance

6E-6 Maint. and MTRL personnel,
plus 3E-6 Cal./Qual. Lab personnel
therefore $9 \times \$26,636 =$ \$239,724

CMI System

Optical scanning equipment
monthly rental = $\$19,575 \times 12 =$ \$234,900

Computer system
monthly rental = $\$21,783 \times 12 =$ \$261,396
\$848,916

INSTRUCTIONAL MATERIAL

Development

30 ET's at average grade E-6-1/2 =
 $\$28,798 \times 30 = \$863,928$ and prorated
by San Diego portion (28 percent) of
total BE and E students = $\$863,928 \times .28 =$ \$241,903

Printing/Reproduction

$\$60,000$ per year prorated for San Diego =
 $\$60,000 \times .28 =$ \$ 16,800
\$258,703

SCHOOL PERSONNEL

Instructors

64 at average grade E-6-1/2 = $\$28,798 \times 64 =$ \$1,843,072

Support

32 at average grade E-6-1/2 = $\$28,798 \times 32 =$ 921,536
\$2,764,608

STUDENTS

Personnel

Calculated on estimates of 7000 entrants/year
and 6000 graduates/year (14 percent attrition),
with average grade of E-3. Assuming average
time on-board of 1.5 mos. for graduates and
.5 mos. for attrites personnel costs =

6000 x	15,302	12 mos. x 1.5 mos plus	
1000 x	15,302	12 mos. x .5 mos =	\$12,114,083

Travel

Calculated based on estimated 15 percent of
7000 students travel to San Diego at average
cost of 100 =

<u>105,000</u>
\$12,219,083

TOTAL TRAINING SYSTEM COSTS PER YEAR =	\$16,410,966
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AVERAGE COST PER GRADUATE (16,410,966 ÷ 6,000) =	\$2,735
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APPENDIX B

LABORATORY TRAINING OBJECTIVES, BE AND E COURSE

APPENDIX B

MODULES 1-14

1. Set up and use Simpson 260 multimeter as a: voltmeter, ammeter, ohmmeter.
2. Set up and use RCA WO-33A oscilloscope and EICO 377 signal generator.
3. Measure: resistance, current, voltage, capacitor charge time.
4. Understand theory and operation of: series circuits, parallel circuits, combination circuits, inductive AC circuits, RC circuits, series LCR circuits, parallel LCR circuits, power transformers, and diodes.
5. Calculate: transformer turns ratio, winding impedance, power supplied and dissipated, voltage, current, and resistance (use Ohm's and Kirchoff's Laws), and RC time constants.

MODULES 15-19

1. Use technical manual for 6B25 receiver as an aid in circuit analysis.
2. Interpret schematic diagrams.
3. Identify components in the 6B25 receiver.
4. Troubleshoot 6B25 radio receiver using a logical signal tracing approach.

5. Set up and use:
 - a. Oscilloscope
 - b. Multimeter
 - c. Signal generator
6. Solder printed circuits.
7. Assemble a 6B25 power supply given components and a breadboard or printed circuit card.
8. Fill out repair forms.

MODULES 20-25

1. Understand theory and operation of power supplies, transistors and vacuum tubes, amplifiers, oscillators, multivibrators, waveshaping circuits, SCR circuits, and UJT circuits.
2. Interpret schematic diagrams.
3. Identify components in the training circuits.
4. Construct circuits from selected components using the 6F16 device and selected templates.
5. Manipulate component values to change output waveforms by adjusting a potentiometer or actually substituting components.
6. Measure and/or calculate: diode front-back ratio; transistor front-back ratio; voltage, frequency, period and wave-form phase relationships from scope trace; and amplifier gain ratio.

7. Interpret abnormal waveforms to localize circuit malfunctions.
8. Troubleshoot faulty circuits to a component level using a multi-meter and oscilloscope.
9. Remove and replace faulty components.
10. Use the technical manuals for the NIDA devices to aid in circuit analysis.

APPENDIX C

TASKS AND EQUIPMENT NOT SIMULATED

APPENDIX C

Simulation was deemed inappropriate for tasks which required only very simple, inexpensive equipment and very limited circuit manipulation. Other tasks, by their very nature (i.e., soldering), were not conducive to a simulation approach. The tasks and equipment not simulated are listed below.

TASKS

- Solder printed circuit boards
- Breadboard power supply
- Test vacuum tubes
- Measure voltage across battery
- Measure current in simple circuit

EQUIPMENT

- Crow kit/NP17205
- Electronics kit/17604
- Tube tester TV-7
- Simple voltmeter
- Simple ammeter
- Vector board

APPENDIX D

DEMONSTRATION COURSEWARE

APPENDIX D

GENERAL INSTRUCTIONS

Your performance in this lesson will be monitored by computer. Thus, there are certain procedures that you must follow in working through the lesson.

First of all, you frequently will be asked to test a point in the circuit with an oscilloscope probe. Immediately after connecting the probe to a particular point, you will be told whether or not your choice of test points is correct (the green "PROCEDURE CORRECT" or the red "PROCEDURE INCORRECT" light on the keyboard will illuminate). If your choice of test points is correct, press the "GO" key on the keyboard and go on to the next step in the lesson. If your choice is incorrect, locate the correct test point, connect the probe, and check the indicator light again. If you are correct, press "GO" and go on with the lesson.

The second task you will perform involves responding to questions in the text. To answer a question, type the question number followed by your answer (a-d), on the Keyboard. If your answer is correct, the green "ANSWER CORRECT" light will illuminate. Then, simply press "GO" and continue on with lesson. If your answer is incorrect, the "ANSWER INCORRECT" light will flash. Think over the question and enter your answer again. If it is correct, press "GO" and proceed with the lesson.

In summary then, always follow the specified procedure in the text, and be sure to press "GO" after each correct test of a point or correct answer to a question.

MULTIVIBRATORS

ASTABLE MULTIVIBRATOR

Set the oscilloscope controls as follows:

TIME DIV/VAR CAL A and B to CAL

TIME DIV A and B to 1 msec

TRIG to EXT DC

VOLTS/DIV A and B to 2

Ensure that toggle switch S1 is set to Position 1. Plug in the astable multivibrator circuit-schematic board. Press GO.

Connect the Channel A probe to TP1 on the schematic board and then to TP1 on the actual circuit. Press GO and answer Question 1.

1. Probe A is recording:
 - a. the output of the Q1 collector.
 - b. the output of the Q2 collector.
 - c. the line voltage.
 - d. the input signal to the circuit.
- Press GO.

Now connect the Channel B probe to TP4 on the schematic and then on the actual circuit. It can be seen from the waveforms that when Q1 conducts, Q2 cuts off. Press GO.

Move the Channel B probe to the base of Q2 on the schematic and then on the circuit. Press GO and proceed to Questions 2-5.

2. What determines the gradual voltage rise from 0 V to +3.2 V at the Q2 base, and thus the length of time Q2 is cut off
 - a. time constant R5C2
 - b. time constant R1C1
 - c. time constant R3C2
 - d. time constant R2C1

Press GO

3. What determines the length of time that Q2 is conducting
 - a. The cutoff time of Q1 which is determined by R3C2.
 - b. The cutoff time of Q1 which is determined by R1C1.
 - c. The input frequency.
 - d. The R2C1 time constant.

Press GO

4. Measure the frequency and period of the signal at TP1.

The frequency and period are:

- a. 16 KHz and 60 μ sec
- b. 1.6 KHz and 600 μ sec
- c. 16.6 Hz and 60 msec
- d. 166 Hz and 6 msec

Press GO

5. To increase the frequency of output from Q2 one would (see below) the resistance in the RC circuits which determine the saturation and cutoff times of Q2.

- a. decrease
- b. increase

Press GO

Now, flip toggle switch S1 to position 2, press GO, and answer Questions 6 and 7.

6. Measure the frequency of the Q2 output waveform. The output frequency is now:

- a. 166 Hz
- b. 3.1 KHz
- c. 31 Hz
- d. 312 Hz

Press GO

7. You can see from the schematic that S1 acts as a variable resistor. Since the output frequency increased, setting S1 to position 2 must have:

- a. increased the resistance in R2-C1 and R3-C2.
- b. decreased the resistance in R2-C1 and R3-C2.
- c. decreased the line voltage.
- d. switched R2 out of the circuit.

Press GO

Set the toggle switch on the faulted astable multivibrator circuit board to Position 1 and plug in the board. Press GO.

Connect the Channel A probe to the Q2 collector output at TP1 and the Channel B probe to the Q1 collector. Obtain ground reference for comparison by flipping the Channel A and the Channel B AC/GND/DC switch momentarily to GND and then back to DC. Obviously, the circuit has stopped oscillating. Both the Q1 and Q2 collectors are resting nearly at ground. Press GO and proceed.

Using Probe B, observe the signal at:

the Q1 base (Press GO)
the Q1 emitter (Press GO)
the Q2 base (Press GO)

8. What might cause the collector, base, and emitter of Q1 plus the collector and base of Q2 to all be at the same low (nearly ground) potential simultaneously and continuously
- a. a bad resistor R2
 - b. an open at the emitter of Q1
 - c. a short circuit between the Q1 collector and emitter
 - d. a bad capacitor C1.

BISTABLE MULTIVIBRATOR

Set the oscilloscope controls as follows:

TIME DIV/VAR CAL to CAL

TRIG to EXT DC

TIME/DIV to 2 msec

VOLTS/DIV A and B to 2

Plug in the bistable multivibrator circuit-schematic board and press GO.

Connect the channel A probe to TP1 and the channel B probe to TP2 on the schematic. Then move the probes to corresponding points on the actual circuit. Press GO and answer questions 1-5.

1. Probe A is recording:

- a. the input or trigger signal to the multivibrator.
- b. the output of the Q1 collector.
- c. the output of the Q2 collector.
- d. the line voltage.

Press GO

2. Probe B is recording:

- a. the output of the Q1 collector.
- b. the output of the Q2 collector.
- c. the input signal.
- d. the line voltage.

Press GO

3. Measure the frequency of the input signal and of the output signal. The input frequency is _____, the output frequency is _____.

- a. 153.8 KHz and 76.9 KHz
- b. 120 Hz and 60 Hz
- c. 153.8 Hz and 76.9 Hz
- d. 153.8 Hz and 153.8 Hz

Press GO

4. The output frequency of the bistable multivibrator is _____ the input frequency.
- a. twice
 - b. one-half
 - c. the same as

Press GO

5. The Q2 collector output is at TP2. The other bistable multivibrator output is at:
- a. TP5
 - b. TP8
 - c. TP6
 - d. TP3

Press GO

Now connect the channel B probe to TP5 and the channel A probe to TP2 on the schematic and then to the corresponding points on the actual circuit. Press GO and proceed to Question 6.

6. Observe the traces on the oscilloscope. What is the relationship between the two multivibrator outputs
- a. The output at TP5 is twice the frequency of the TP2 output.
 - b. The output at TP5 is identical to the TP2 output.
 - c. The output at TP5 is the same frequency as the TP2 output, but is 180 degrees out of phase with it.
 - d. The output at TP5 is the same frequency as the TP2 output, but is 90 degrees out of phase with it.

Press GO

Move the channel B probe to the base of Q2 (TP4) on the schematic and then to its corresponding point on the actual circuit. Press GO and proceed to Question 7.

7. The negative-going part of the signal recorded at the Q2 base represents:
 - a. The trigger (delivered through C4 and CR2) that shifts Q2 from saturation to cutoff.
 - b. The trigger (delivered through C4 and CR2) that shifts Q2 from cutoff to saturation.

Press GO.

Connect Probe A to the Q1 collector (TP5) and Probe B to the base of Q1 (TP7) on the schematic. Then move the probes to corresponding points on the actual circuit. Press GO and answer Question 8.

8. The negative-going part of the signal recorded at the Q1 base represents:
 - a. the trigger (delivered through C1 and CR1) which shifts Q1 from saturation to cut-off.
 - b. the trigger (delivered through C1 and CR1) which shifts Q1 from cutoff to saturation.

Press GO

Remove the board and replace it with the faulted bistable multivibrator circuit board. Press GO.

Connect Probe A to the input at TP1 and note that the input waveform is normal. Press GO.

Move Probe A to TP2 and observe that the waveform is no longer a square wave. Flip the Ch. 1 AC/GND/DC switch to GND and note ground reference. Flip the switch back to DC and observe the ~~TP2 signal in~~ relation to ground. Press GQ.

Connect Probe B to the Q1 collector. Momentarily, flip the Ch. 2 AC/GND/DC switch to GND and note ground reference. Flip the switch back to DC and observe the Q1 collector signal in relation to ground. Press GO and answer questions 9 and 10.

9. It appears that:

- a. Q1 is being held in saturation while Q2 is held in cutoff.
- b. Q2 is being held in saturation while Q1 is held in cutoff.

Press GO.

10. Given the following possibilities, the malfunction is most likely in:

- a. voltage divider network R7-R5-R4.
- b. voltage divider network R1-R3-R6.
- c. the voltage line.

The problem in the circuit in fact lies in R1, which is opened. Since the R1-R3-R6 network is opened at R1, the only path for current is the R7-R5-R4 network. When Q2 cuts off, current flows through that network, triggers Q1 into saturation, and holds it there. Q2 stays in cut-off.

MONOSTABLE MULTIVIBRATOR

Set the oscilloscope controls as follows:

TIME DIV/VAR CAL A and B to CAL

TIME/DIV A and B to 2 msec

TRIG to EXT DC

VOLTS/DIV A and B to 2

Ensure that toggle switch S2 is set at Position 1 (up) and plug in the monostable multivibrator circuit-schematic board. Press GO.

Connect the Channel A probe to TP1 and the Channel B probe to the input at TP7 on the schematic. Then move the probes to the corresponding points on the actual circuit. Press GO and proceed to Questions 1 and 2.

1. Probe A is recording:
 - a. the line voltage
 - b. the signal at the base of Q2.
 - c. the output of the Q2 collector.
 - d. the Q2 emitter signal.

Press GO

Before going on to Question 2, sketch the TP1 and TP7 waveforms in your notebook.

2. A positive-going output pulse is generated at TP1 each time the input:

- a. goes negative
- b. goes positive

Press GO.

Now connect Probe A to the collector of Q1 and Probe B to TP7 on the schematic and then on the actual circuit. Record the waveform and press GO. Go on and observe the signal at the base of Q2 using Probe A, with a Probe B reference at TP7. Sketch the waveform and press GO.

Compare the waveforms you have sketched. Note that the positive-going input pulse causes Q1 to saturate. The Q1 collector voltage drops from +3.2v to 0v which causes the Q2 base to go negative also. The final result of this chain of events is that Q2 cuts-off and its collector voltage rises to +3.2v.

Reconnect Probe A to TP1 and press GO, and answer Questions 3 and 4.

3. Observe the Channel A trace on the scope and measure the width of the positive-going output pulse at TP1. The pulsewidth is:

- a. 180 sec
- b. 9 msec
- c. 1.8 msec
- d. 18 msec

Press GO

4. If you wanted to decrease the width of the output pulse at TP1 you would:

- a. increase the resistance in the RC network that determines pulsewidth.
- b. decrease the line voltage.
- c. decrease the resistance in the RC network that determines pulsewidth.
- d. increase the frequency of the input trigger.

Press GO

Flip toggle switch S2 to position 2, press GO, and proceed to Questions 5 and 6.

5. Observe the Channel A trace and measure the width of the output pulse at TP1. You may wish to expand the time-base using the TIME/DIV control before making the measurement. The pulsewidth is:

- a. 12 msec
- b. 6 msec
- c. 6 sec
- d. 0.6 msec

Press GO

6. You can see from the schematic that S1 acts as a variable resistor. Since the output pulsewidth decreased, setting the switch to position 2 must have:

- a. decreased resistance in the R8-R6 network.

- b. decreased resistance in the R7-C3 networks.
- c. increased resistance in the R8-R6 network.
- d. increased resistance in the R7-C3 network.

Remove the board and plug in the faulted monostable multivibrator circuit board. Ensure that the toggle switch is in Position 1. Press GO.

Connect Probe A to the input at TP7 and press GO. You can see that the input signal is the same as in the normal board.

Now connect Probe A to the Q2 collector and Probe B to the Q1 collector. Obtain and note ground reference for each trace by momentarily flipping the AC/GND/DC switch for each channel to GND and then back again to DC. The circuit is clearly not putting out timed pulses. Compare the traces and note that the Q2 collector is resting at a high positive voltage. Sufficient current is apparently flowing through R6 to keep Q1 saturated and at a low voltage. Press GO and proceed with the circuit analysis.

Connect Probe B to the base of Q2 and press GO. Then move Probe B to the Q2 emitter. Press GO.

- 7. The emitter and base of Q2 are both being held:
 - a. low
 - b. high
- Press GO

Connect Probe A to the Q1 collector, and connect Probe B to the Q1 base. Press GO and move Probe B to the Q1 emitter. Press GO and proceed to Questions 8 and 9.

8. The Q1 base and emitter are being held:

- a. low (nearly at ground).
- b. high.

Press GO

9. This particular set of circumstances would be present if:

- a. the emitter and collector of Q2 were shorted.
- b. the emitter and collector of Q1 were shorted.
- c. the emitter of Q2 were opened.
- d. the emitter of Q1 were opened.